NASA Administrator
Daniel S. Goldin

"Tools of the Future"
January 13, 1998

Everyone knows that at NASA, we're about opening the air and space frontiers. What they sometimes forget is that we're also about designing and building the tools that are required to do that.

But that's what we do at NASA . . . time after time. And I'm especially proud -- and you should be, too -- of the progress we've made in this era of decreasing budgets and downsizing.

We need no more proof than the year that has just passed.

But we also know that we can't stop now. We still want to cut system costs by about an order of magnitude. Cut cycle time of development by a factor of 3 to 5. Improve reliability by up to a factor of 10,000. And at the same time getting back a higher quality of science and engineering products.

Cost. Cycle time. Safety. Quality products. These, of course, are not only challenges for NASA. They are challenges that people all over the country face.

So today, I want to show you not necessarily where we are . . . but where we are going. And not just at NASA. But in the entire field of engineering.

I have divided my presentation into four pieces.

First, I will speak about NASA's vision.

After that, I will go into future characteristics of the systems that will make that vision possible.

Then, I will speak about the current engineering design culture.

And finally, I will discuss the revolution. What we call "ISE." Intelligent Synthesis Environments. The future of engineering.

So let's get started.

At NASA, as all of you know, we are divided into four strategic activities. (for those of you who don't know that, don't worry . . . I know who you are.)

We work in Space Science, which is understanding our universe and our solar system. Earth Science is to understand our own planet. Aeronautics and Space Transportation. And finally, Human Exploration.

I'll begin in aeronautics and space transportation. . . first with global civil aviation.

Aeronautics is the number one manufactured export for America. It is absolutely essential to the future vitality of the American economy.

That's why we want to answer the following question:

How can we enable revolutionary technological advances to provide air and space travel for anyone, anytime, anywhere in the world more safely, more affordably, and with less impact on the environment and improve business opportunities and global security?

Safety.

Together, we must come up with the technologies for advanced crew interface. We must give pilots situational awareness of their surroundings. That means real-time weather . . . terrain. . . and on board air traffic control.

The work has already begun . . . in the next 10 years our goal is to cut the fatal crash rates for planes by a factor of 5 . . . and in 20 years a factor of 10.

And while we're improving safety, we also want to improve the air space capacity.

There's a crisis coming because of the demand for aircraft and the current limitations of the infrastructure.

So we're going to triple the through-put . . . day/night . . . all weather . . . still maintaining safety and reliability.

Affordability.

The costs of air travel keeps going up . . . from acquisition to operations.
And the revenues keep going down. For example, in the last 20 years the cost of aircraft have gone up 50 percent.

In 10 years, we intend to cut the cost of air travel by 25 percent, and in the next 20 years cut it by 50 percent. Those are the goals.

Environment.

We're going to cut the noise of airplanes by a factor of 2 in 10 years, a factor of 4 in 20 years. Planes will be so quiet in 20 years, busses and trucks will make more noise than the planes landing at airports.

And we're going to cut the emissions in the planes a factor of 3 in 10 years, a factor of 5 in 20 years.

(Keep in mind, these are technology goals . . . we must first validate at full scale our advancements in environment . . . . while maintaining safety levels and economy of operations before considering any regulatory action.)

Technology.

We are looking at a major revitalization of the general aviation industry . . . including new concepts for advanced personal aircraft.

On the right, you can see what we hope will be a relatively low-cost personal business jet.

In the late 70s, we produced almost 20,000 general aviation planes a year. Right now we produce only 1000 general aviation planes a year.

That's not good enough. In fact, it's terrible.

We want to take the technology leaps that will allow us to produce 10,000 aircraft a year in ten years . . . and 20,000 a year in 20 years.

We want to produce general aviation jet planes as safe as long-haul jet aircraft. And instead of millions dollars . . . they will cost closer to hundreds of thousands of dollars.

We want to be able to travel at supersonic speeds. Mach 2.5. Within 20 years, we'll reduce travel time by 50 percent . . . without seriously impacting our environment. And our goal is that we will keep the costs close to today's subsonic transport levels.

And finally, we want and need to develop the design tools that will allow us to cut the cycle time of long-haul jet transports by a factor of 2.

Access to Space.

America has not produced a new launch vehicle or rocket in 25 years . . . yet we've spent tens of billions of dollars on the Shuttle. Don't get me wrong, I think the Shuttle is a wonderful machine. But the commercial space communication industry is white hot and can't afford the current launch costs.

The cost and reliability of access to space is the number one barrier to opening the space frontier . . . for commercial, civil and military activities.

That's why it is our first priority for new development activity.

Specifically, our ten year goal is to develop the technology for launch vehicles such that American suppliers will be able to build launch vehicles that will cut the cost of taking payloads to orbit by a factor of 10.

By 2020, we'll cut cost by a factor of 100. And we'll improve reliability by a factor of 10,000.

Earth Science.

We want to use a fleet of spacecraft and various instruments to help us answer the question: How can we use the knowledge of the Sun, Earth and other planetary bodies to develop predictive environmental, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Here are a few examples of the kind of things we're measuring. For instance, it was a NASA satellite that confirmed the existence of the Antarctic ozone hole in 1985 and has monitored its size since then.

Future missions will give us even more insight into the dynamic processes that impact our planet.

Here's another example -- one of the biggest stories of the year.

NASA has developed a series of satellites -- the first measured ocean temperatures. NOAA -- the National Oceanic and Atmospheric Administration -- has been monitoring those for some time.

Then working in partnership with the French, because this is a global challenge, we have developed a satellite called Topex Poseidon. It is providing the most precise measurements ever of ocean surface height . . . within a few inches . . . an amazing breakthrough.

Finally, last year, on a Japanese satellite, we launched what we call a Scatterometer. It is a microwave device that measures the wind velocity and the wind direction on the surface of the ocean for the first time.

Correlating the measurements from these three spacecraft . . . we were able to predict -- for the very first time -- an El Nino condition . . . a seasonal weather prediction.

A final example is being able to track hurricanes from space.

Some have estimated that since 1925, Hurricanes have caused an average of $5 billion in damage annually in the United States.

But if we can predict . . . we can prepare. Maybe even prevent.

For each hour of advanced warning . . . millions are saved.

So we've set these goals: within 10-15 years, we want to be able to predict the weather, climate and natural disasters with a much higher accuracy, and we want to be able to make forecasts on a seasonal to inter-annual basis.

And hopefully within 25 years, we'll be able to make multi-decade predictions of climate and environment, so we can better manage our resources for sustainable development . . . globally, regionally, and locally.

In Space Science,

We are going to continue to send "Faster, Better and Cheaper" spacecraft to hopefully establish a virtual presence throughout our solar system.

And hopefully, within about 10-15 years, we'd like to robotically visit every key planetary body in our solar system and bring back samples from the scientifically significant ones.

At the same time, we will be studying the Sun-Earth connection . . . how solar activity effects our climate and our electromagnetic environment.

We want to learn more about the structure of the universe. We hope to shed some light on its mysteries that have eluded us . . . like the presence of black holes at the center of galaxies. We want to know if the universe will expand forever . . . or will it, one day, collapse.

Within about ten years we hope to replace the Hubble Telescope and other observatories with revolutionary telescopes that have significantly better spatial and spectral resolution than their predecessors . . . at a fraction of the weight and at a fraction of the cost.

Some will be so advanced that in the next 10 to 15 years we intend to directly detect Earth-sized planets around stars within 100 light years of Earth.

Now if these planets exist, these telescopes should be able to pick up the signs of whether or not they are conducive to life.

And within 25 years, we've set what today looks like an impossible goal . . . that if these planets exist, and we're able to isolate them . . . we'd like to be able to take a picture with the resolution high enough to see oceans, mountain ranges, cloud cover, and continents.

All of these important missions will help us answer the age old questions: What are the origins of our universe? How did galaxies, stars and planets evolve?

Are there Earth-like planets beyond our solar system? Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on planet Earth?

Are we alone?

A quick note before I move onto the final enterprise. At Ames, we have established an Astrobiology Institute . . . because we must integrate biological science into our search for life processes throughout the universe.

Right now, the scientific community is not doing enough in this area. But I'm confident that NASA will lead the way.

Finally, the area of Human Exploration.

This year, we will launch the first piece of the International Space Station . . .
the largest peacetime scientific and technological project in history . . .

and the foundation for what will be a multinational, permanent human presence in space.

It's really something else . . . the ISS will have a pressurized volume of laboratory space equivalent to two jumbo jet airlines. It will have a hundred kilowatts of electricity. In overall size, we'll have something larger than a football field in orbit.

But what is most important is not hardware. It is that the ISS will present scientists, engineers and entrepreneurs the chance to perform complex, long-term and repeatable experiments in space.

And because of the absence of gravity's effects -- or micro-gravity -- these experiments will hopefully lead to improvements in industrial processes. . . increasing fundamental knowledge in areas like, physics . . . and advancements health care in ways we cannot even begin to imagine.

One final example of how we're going to use the International Space Station. The International Space Station will be the testbed, indeed the platform, for the next step in exploration.

We want to integrate the knowledge we gain from our robotic missions with the lessons we have learned on the ISS . . . and leave Earth orbit.

This will lead to an affordable integration of our science and human exploration strategy.

Because we want to go to Mars. And when we're ready . . . when our government is ready . . .

when we know we have the engineering capability and we can do it safely . . .

when we know there's science to be gained and when we can do it for an acceptable cost . .

we are going to one day crunch our boot on the dusty surface of the Red Planet.

(And in case you were wondering . . . and if you look at the image in the bottom right hand corner . . . I'm the one jumping up and down.)

That's the NASA vision.

Now -- clearly -- we need to think about the future characteristics of the systems that will make our vision a reality.

We need more intelligent systems. More flexible modular vehicles. Breakthroughs in miniaturization. Better, lighter materials. . . that can withstand the most extreme environments. And advanced operating capability.

We want to send a probe that will go to the edge of our solar system . . . interstellar space a tenth of a light-year away. . . and ultimately to a near-by star.

This will need revolutionary propulsion systems.

But it will also need to be a thinking, intelligent spacecraft. It will be too far away for operational commands to come from Mission Control. At the speed of light, it will take months to relay the simplest communications.

This means a radical change for communications and operations.

Space systems of the future need to learn and adapt as they go. There will be real-time damage assessment because the decisions are being made by the spacecraft themselves. They will be self-diagnostic . . . and self-repairing.

This same kind of technology will find its way into vehicles operating closer to Earth and within the Earth's atmosphere.

In many ways they will be like the human body. They'll have sensors and actuators. They will react to stimuli. And they will have a distributed nervous system with intelligence that enables them to react and adjust according to changing environments.

These environments are filled with uncertainty . . . so our traditional numerical approaches will not work. Instead, they will require implementing what is commonly referred to as soft computing.

This takes us from traditional engineering, numerical calculations . . . . through processes that more closely resemble human intelligence.

Now to measure performance, we need to establish a concept of vehicle IQ as part of our engineering design process.

Going to the furthest reaches of the solar system and beyond will also require smaller and cheaper spacecraft and systems.

We've already made significant strides.

Viking for instance, cost over $ 3 billion in today's dollars . . . and took about a decade to develop. It was about the size of a car.

By contrast, the Mars Pathfinder took a quarter of the time to develop. It cost less than one-tenth as much, and it was a fraction of the size.

The Pathfinder was just the first of what will be a continuous robotic presence on Mars for at least the next decade. The costs and the size of the spacecraft systems keeps coming down . . . but capability keeps going up.

We plan to get the size of one of these spacecraft down to about the size of an average television. Ultimately, we are talking about spacecraft -- nano-spacecraft -- that weigh less than one kilogram. They will fit in the palm of your hand. The entire avionics will be on one chip.

We will also need to drive materials and design tools . . . because these missions will be operating in some of the harshest environments. We will be entering atmospheres at heating rates 10 times higher than Apollo encountered on Earth reentry.

Right now, for instance, the limiting operating temperature inside critical components of aircraft engines -- or rockets or high-alloy car engines -- is about 1700 degrees.

In the future, with advanced materials like ceramic composites, we'll bring that temperature up to about 3000 degrees.

That will mean significant improvements not only in fuel consumption . . . but in emissions . . . and reliability. And at the same time, we will bring down the weight and cost.

A moment ago, I mentioned Apollo. Back then, apart from the few astronauts in the spacecraft, all of the brain power was on the ground. But if we're sending humans to Mars -- or anyplace millions of miles away -- communications are going to take too long.

So at NASA, we want to develop fully autonomous outposts.

If you think about the Shuttle Mission Control . . . for every person you see, there are many others backing them up. Launching the Shuttle takes thousands of people . . . and hundreds of millions of dollars.

I'll use the Pathfinder again for contrast. From beginning to end . . .that mission took about 50 people. Total. Future missions will require only a dozen or so.

As we move into the future . . . the days of 100 to 1000 people in the back room will be something of the past.

That's what I mean when I talk about a "faster, better, cheaper" NASA.

Just think of the impact advanced information technologies and other breakthroughs will have on power plant operations . . . on package delivery businesses . . . and on the automotive industry.

These are the tools we need.

Now the question is, how do we get from here to there? Not just from Earth to Pluto. But from where engineering design culture is today . . . to where it needs to be -- and must be -- for the missions of tomorrow.

For a long time, engineering was a pencil to paper culture. Everything was based on classical engineering theory transferred into handbooks. And for those of you too young to remember . . . in the lower left-hand corner, you will see an antiquated device we called the slide rule. That's what I trained with.

In the 60s, we went to the electronic drafting boards that provided wireframe computer modeling. We used major mainframe computers and the analytical model interaction was through data cards and punch cards.

From there we went to distributed terminals . . . using light pens and touch screens.

In the mid 70s, we were using solid models to represent geometry and three-dimensional surface contours.

The major problem was the incompatibility of individual discipline analytical models with the geometric structural representation.

Too much time and resources were wasted on developing translational capability between diverse disciplines . . . like aerodynamics . . . thermal . . . structures and controls.

The traditional design process was sequential with separate discipline groups. We used individual analytical tools and system design was optimized at the discipline level not the system level.

Data and design information had to be moved from one group to another . . . a task accomplished by people carrying large piles of paper.

I'm sure there are a few of you who remember the many large mylar drawings used for manufacturing. (this was our transfer device . . . That's why God gave us engineering change orders)

About 20 years ago, we merged the design process with manufacturing -- the emergence of CAD/CAM.

This significantly reduced design cycle, process time and engineering change orders.

This trend has led to concurrent engineering -- the use of digital data sets for linking diverse disciplines.

The best example for concurrent engineering is the Boeing 777 aircraft development. At the peak of design work, 238 design teams involving 6,000 engineers . . . using data from 4,000 world-wide computer terminals . . . manipulated 3 trillion bytes of information . . . that represented 20,000 design releases.

It can be a bit overwhelming.

Today, we have very efficient and qualified product teams. But we still have a disconnect from discipline to discipline. We still don't have a common database . . . but rather many distributed, unconnected databases across engineering disciplines and manufacturing.

NASA is working hard to break this log-jam.

We have what we call our Product Design Center at the Jet Propulsion Laboratory. By bringing disciplines together, it has provided us with the ability to reduce analysis of mission design concepts from half a year to two weeks.

Now, this only includes preliminary design. We have yet to hit detailed design, manufacturing and operations. That's next. And industry is already working on some of these specific, near-term, focused areas.

Boeing is looking at simulating manufacturing of both fighters and transport aircraft.

One of their programs, called DMAPS, is focusing on engineering realism in modeling and incorporating it into producable aircraft.

Boeing is also looking at simulating the manufacturing process for large scale transports.

And Lockheed Martin is looking at how they can use this technology to create a virtual product manufacturing environment for the F-22. (pause)

Despite all of this effort, we still can't do total end-to-end product life cycle simulation.

That is a broad goal for NASA.

First, because of the sequential nature and limitations of our tools, there is still far too much uncertainty throughout the life cycle of a product.

Second, there's a lot of people involved. And we have just begun to address the geographically distributed nature of what we do.

Third, a point that really binds the first two, is that we need to capture design knowledge earlier in the design process.

And fourth -- the biggest challenge yet -- learning to deal with the unprecedented quantity of data and converting it into usable knowledge . . . finding the information needle in the electronic haystack. Having the database information we need. . . when we need it.

Given these four issues, the problem NASA and industry faces in developing a product is we have to commit a large percentage of the cost . . . when we only have a small percentage of knowledge.

And the more we commit and incur costs in any design process, our flexibility to make necessary changes diminishes. We can make the changes . . . but only at the risk of overrunning cost and schedule. The result, sadly, is that we don't get an optimized design.

We're making progress . . . we're not where used to be. But we're not where we ought to be either.

So I'd like to share with you what I think we need to do close the gap between design knowledge and cost commitments.

We call it the Intelligent Synthesis Environment.

It's not just updating tools. It's fundamentally changing the culture of engineering.

Right now, we have research activities going on in advanced computing and human interaction with the computing environment . . . virtual presence and product development . . .and knowledge-based engineering and computational intelligence.

The challenge -- if NASA's going to reach our goals . . . and if our country is to lead the world in new products and applications -- is to integrate these activities into a vision for future science and engineering.

Because if we do that, we will establish a revolutionary leap in engineering . . . the ability to conduct entire life-cycle simulation at any required fidelity scale.

That's what ISE is about.

These are the major components.

The first two deal with human computer interaction in a distributed, collaborative environment.

The other two have to do with the new simulation tools . . . and how we incorporate these tools into a seamless life cycle system capability.

And finally the key element -- the cultural change I think we need to inject into the creative process.

I'll discuss each of these elements.

First, human interaction. Simply put, this deals with the dynamics and interfaces between the human being and the computer.

What you are looking at right now are some examples of how virtual reality can be used today. As a field, virtual telepresence is advancing -- both in two and three-dimensional representations.

The Vision Dome, for example, is one of the most advanced concepts to date. It allows you to view things in full-scale 3-D without devices, like glasses, head trackers and wands

Unfortunately, most of the applications have been in the entertainment area . . . not engineering.

We need to be able to simulate and visualize our engineering processes in real-time with full, interactive control.

The way we interface with computing today is for WIMPS -- Windows. Icons. Menus. Pointing Systems.

But this is not the way we deal with our environment.

In the real world, we make decisions based on all of our senses. We interact and process various sources of information.

You can't drive cars this way. You can't fly an airplanes this way.

At NASA, we know that WIMPS won't get us to Mars.

Presently, virtual reality deals with sight/sound only. In the future it will encompass all of the senses -- including smell and touch.

That's why currently, we need to exploit the research being done to understand the brain's cognitive processes.

Hopefully, soon we will be able to use this knowledge to bring together the computer user and the computer environment to maximize performance.

Imagine operating a computer the same way we deal with our daily environment -- using all of our senses to shape our thoughts and actions.

This isn't the computer controlling humans . . . it's the exact opposite. It's maximizing performance of computational capability.

In fact, the Air Force is already looking at how this kind of advancement can help their pilots.

Another step we must take in the area of human interaction with computers is moving from data . . . to information . . . to knowledge . . . to intelligence.

This isn't just semantics. Think of pilots.

They will have a lot of data in front of them. Temperature. Pressure. Wind speed.

Our pilot puts this data together and determines what is going on . . . maybe an engine is overheating because of a defective fuel valve.

Further processing provides the knowledge . . . why this is happening.

And finally intelligence is when we know what to do about it **before** a failure occurs . . and how to prevent it from happening in the future.

Next -- building the infrastructure for distributed collaboration so we can take full advantage of diverse teams around the world.

We have been working with the Department of Energy on their Accelerated Strategic Computing Initiative. It's looking at how we can develop teraflop capability in performance.

That's a good start. But we need to get to a hundred to a thousand-fold increase -- petaflop capability . . . perhaps even beyond -- for the ISE vision.

We need to move into non-silicon, or non-electric, computers. Maybe they will include both optical and biological computing.

We also need to increase our networking capability.

The amount of information flowing through the pipeline needs to increase from under a gigabit . . . where it is today . . . to one hundred to one thousand gigabits per second . . . or even higher.

There will be actual intelligence in the switchers and routers . . . or intelligent interfaces . . . something that doesn't exist in today's Internet.

And this increased networking ability will enable us to link computers, mass storage facilities, and people seamlessly.

The Department of Defense has a program that is a starting point for how we link diverse teams together in a simulation-based conceptual design environment.

But we can take it a step further . . . into a high fidelity . . . high information content . . . distributed . . . virtual environment.

We can have a team in the northeast . . .

a team in the south . . .

and a team in the west . . .

all working together on the same project in a virtual design space.

Instead of taking the "Red Eye" teams can come and go electronically.

More important . . . this provides us with something that has been missing for too long.

In today's engineering culture, due to limitations in our models, we over-simplify the real world . . . and we rely on separate complimentary test programs to establish worst case operating and failure conditions.

In order to account for the uncertainty and to quantify the risk level, we need to move from the traditional deterministic methods to non-deterministic methods . . . like probabilistic approaches . . . neural networks . . . genetic algorithms and symbolic computing.

We have already achieved a very high level of sophistication in numerical simulations across many disciplines.

But what we need now is an even more rapid analysis and optimization capacity so we can close the design knowledge - cost commitment gap, I spoke about earlier.

Let's look at an example of both non-traditional methods and applications.

First a non-traditional method: neural networks -- which have the capacity to learn or adapt analogous to the human brain.

This graph shows the capability of current neural networks.

Today's technology limits us to about one billion nodal connections . . . and one billion nodal interactions per second.

But the human brain is more than one million times more powerful than that.

In other words, we have a lot of work in front of us. But we also have the potential for a very high pay-off.

Neural networks and other non-traditional methods will help us analyze and design systems, like smart materials and devices. Systems like these would overwhelm any traditional design synthesis approach.

It could involve material modeling that will allow us to design devices that integrate various physical properties . . . such as mechanical . . . electrical . . . magnetic . . . and thermal.

These devices can sense and respond to stimuli. For instance they will be able to adjust the shape of aircraft wings, suppress engine vibrations and control sensitive optics.

This will begin with the quantum mechanics of the individual atom. We will then synthesize molecules and begin to understand their interaction.

From there we will develop a better understanding of basic physical phenomena.

And ultimately, we will model entire large-scale processes leading to engineering design applications. And this will be done atom by atom.

This approach will dramatically shorten the cycle time of product development by enabling a seamless flow from initial concept through final design and manufacturing. We hope to eliminate the sequential design process of today.

To date, industry has concentrated on simulation of manufacturing, planning and processes only.

We have simulators of the individual machine. And we have real time assessment of inventory flow control.

But we need to be able to simulate an entire factory before we build it.

From there, we can begin to simulate the operations. . . including repairs and how we maintain a system. On the screen, you can see of how they're beginning to do this at Marshall on the X-34.

This advanced simulation also provides us with a unique opportunity to look at training at the virtual prototype level . . . before any hardware is in place. This is being used at Johnson for space station training.

That brings us to the fourth component of ISE -- how do we achieve this future engineering capability?

To this point, there are a lot of unknowns. In these virtual environments, we don't know what fidelity we need. We don't know what scale is required. We just don't know yet how these collaborative, virtual teams are going to work.

These are fundamental issues.

So, to address these fundamental issues and demonstrate this future collaborative design environment, we are looking to establish national . . . virtual . . . distributed testbeds.

These testbeds are like nothing you've ever seen before.

They are geographically distributed computing environments that integrate hardware-in-the-loop . . . real time information operating systems . . . and all associated engineering design tools.

At NASA, we want to focus these testbeds in critical areas such as a high speed civil transport . . . reusable launch vehicles . . . Next Generation Space Telescopes . . . and human exploration to Mars.

And clearly, we want broad industry and academic involvement. Because this is not just about the aerospace industry.

I've dealt with the technical barriers.

Now the cultural barrier.

We need to realize that this is not just about technology. It's about people . . . and how people work and communicate on a global scale.

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But that's what we do at NASA . . . time after time. And I'm especially proud -- and you should be, too -- of the progress we've made in this era of decreasing budgets and downsizing.

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On the right, you can see what we hope will be a relatively low-cost personal business jet.

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We want to take the technology leaps that will allow us to produce 10,000 aircraft a year in ten years . . . and 20,000 a year in 20 years.

We want to produce general aviation jet planes as safe as long-haul jet aircraft. And instead of millions dollars . . . they will cost closer to hundreds of thousands of dollars.

We want to be able to travel at supersonic speeds. Mach 2.5. Within 20 years, we'll reduce travel time by 50 percent . .. without seriously impacting our environment. And our goal is that we will keep the costs close to today's subsonic transport levels.

And finally, we want and need to develop the design tools that will allow us to cut the cycle time of long-haul jet transports by a factor of 2.

Access to Space.

America has not produced a new launch vehicle or rocket in 25 years . .. yet we've spent tens of billions of dollars on the Shuttle. Don't get me wrong, I think the Shuttle is a wonderful machine. But the commercial space communication industry is white hot and can't afford the current launch costs.

The cost and reliability of access to space is the number one barrier to opening the space frontier . . . for commercial, civil and military activities.

That's why it is our first priority for new development activity.

Specifically, our ten year goal is to develop the technology for launch vehicles such that American suppliers will be able to build launch vehicles that will cut the cost of taking payloads to orbit by a factor of 10.

By 2020, we'll cut cost by a factor of 100. And we'll improve reliability by a factor of 10,000.

Earth Science.

We want to use a fleet of spacecraft and various instruments to help us answer the question: How can we use the knowledge of the Sun, Earth and other planetary bodies to develop predictive environmental, climate, natural disaster, and natural resource models to help ensure sustainable development and improve the quality of life on Earth?

Here are a few examples of the kind of things we're measuring. For instance, it was a NASA satellite that confirmed the existence of the Antarctic ozone hole in 1985 and has monitored its size since then. Future missions will give us even more insight into the dynamic processes that impact our planet.

Here's another example -- one of the biggest stories of the year.

NASA has developed a series of satellites -- the first measured ocean temperatures. NOAA -- the National Oceanic and Atmospheric Administration -- has been monitoring those for some time.

Then working in partnership with the French, because this is a global challenge, we have developed a satellite called Topex Poseidon. It is providing the most precise measurements ever of ocean surface height . . . within a few inches . . . an amazing breakthrough.

Finally, last year, on a Japanese satellite, we launched what we call a Scatterometer. It is a microwave device that measures the wind velocity and the wind direction on the surface of the ocean for the first time.

Correlating the measurements from these three spacecraft .. . we were able to predict -- for the very first time -- an El Nino condition . . . a seasonal weather prediction.

A final example is being able to track hurricanes from space. Some have estimated that since 1925, Hurricanes have caused an average of $5 billion in damage annually in the United States.

But if we can predict . . . we can prepare. Maybe even prevent.

For each hour of advanced warning . . . millions are saved. So we've set these goals: within 10-15 years, we want to be able to predict the weather, climate and natural disasters with a much higher accuracy, and we want to be able to make forecasts on a seasonal to inter-annual basis.

And hopefully within 25 years, we'll be able to make multi- decade predictions of climate and environment, so we can better manage our resources for sustainable development . .. globally, regionally, and locally.

In Space Science.

We are going to continue to send "Faster, Better and Cheaper" spacecraft to hopefully establish a virtual presence throughout our solar system.

And hopefully, within about 10-15 years, we'd like to robotically visit every key planetary body in our solar system and bring back samples from the scientifically significant ones.

At the same time, we will be studying the Sun-Earth connection . . . how solar activity effects our climate and our electromagnetic environment.

We want to learn more about the structure of the universe. We hope to shed some light on its mysteries that have eluded us . . . like the presence of black holes at the center of galaxies. We want to know if the universe will expand forever . . . or will it, one day, collapse.

Within about ten years we hope to replace the Hubble Telescope and other observatories with revolutionary telescopes that have significantly better spatial and spectral resolution than their predecessors . . . at a fraction of the weight and at a fraction of the cost.

Some will be so advanced that in the next 10 to 15 years we intend to directly detect Earth-sized planets around stars within 100 light years of Earth.
Now if these planets exist, these telescopes should be able to pick up the signs of whether or not they are conducive to life.

And within 25 years, we've set what today looks like an impossible goal . .. that if these planets exist, and we're able to isolate them . . . we'd like to be able to take a picture with the resolution high enough to see oceans, mountain ranges, cloud cover, and continents.

All of these important missions will help us answer the age old questions: What are the origins of our universe? How did galaxies, stars and planets evolve?

Are there Earth-like planets beyond our solar system? Does life in any form, however simple or complex, carbon-based or other, exist elsewhere than on planet Earth?

Are we alone?

A quick note before I move onto the final enterprise. At Ames, we have established an Astrobiology Institute . .. because we must integrate biological science into our search for life processes throughout the universe.

Right now, the scientific community is not doing enough in this area. But I'm confident that NASA will lead the way.

Finally, the area of Human Exploration.

This year, we will launch the first piece of the International Space Station . . . the largest peacetime scientific and technological project in history . . . and the foundation for what will be a multinational, permanent human presence in space.

It's really something else . . . the ISS will have a pressurized volume of laboratory space equivalent to two jumbo jet airlines. It will have a hundred kilowatts of electricity. In overall size, we'll have something larger than a football field in orbit.

But what is most important is not hardware. It is that the ISS will present scientists, engineers and entrepreneurs the chance to perform complex, long-term and repeatable experiments in space.

And because of the absence of gravity's effects -- or micro- gravity -- these experiments will hopefully lead to improvements in industrial processes. . . increasing fundamental knowledge in areas like, physics . . . and advancements health care in ways we cannot even begin to imagine.

One final example of how we're going to use the International Space Station. The International Space Station will be the testbed, indeed the platform, for the next step in exploration.

We want to integrate the knowledge we gain from our robotic missions with the lessons we have learned on the ISS . .. and leave Earth orbit.

This will lead to an affordable integration of our science and human exploration strategy.

Because we want to go to Mars. And when we're ready . .. when our government is ready . . . when we know we have the engineering capability and we can do it safely . . . when we know there's science to be gained and when we can do it for an acceptable cost . . . we are going to one day crunch our boot on the dusty surface of the Red Planet.

(And in case you were wondering . . . and if you look at the image in the bottom right hand corner . . . I'm the one jumping up and down.)

That's the NASA vision.

Now -- clearly -- we need to think about the future characteristics of the systems that will make our vision a reality.

We need more intelligent systems. More flexible modular vehicles. Breakthroughs in miniaturization. Better, lighter materials. . . that can withstand the most extreme environments. And advanced operating capability.

We want to send a probe that will go to the edge of our solar system . . . interstellar space a tenth of a light-year away. . . and ultimately to a near-by star.

This will need revolutionary propulsion systems.

But it will also need to be a thinking, intelligent spacecraft. It will be too far away for operational commands to come from Mission Control. At the speed of light, it will take months to relay the simplest communications.

This means a radical change for communications and operations.

Space systems of the future need to learn and adapt as they go. There will be real-time damage assessment because the decisions are being made by the spacecraft themselves. They will be self-diagnostic . . . and self-repairing.

This same kind of technology will find its way into vehicles operating closer to Earth and within the Earth's atmosphere. In many ways they will be like the human body. They'll have sensors and actuators. They will react to stimuli. And they will have a distributed nervous system with intelligence that enables them to react and adjust according to changing environments.

These environments are filled with uncertainty . . . so our traditional numerical approaches will not work. Instead, they will require implementing what is commonly referred to as soft computing.

This takes us from traditional engineering, numerical calculations . . . . through processes that more closely resemble human intelligence.

Now to measure performance, we need to establish a concept of vehicle IQ as part of our engineering design process.

Going to the furthest reaches of the solar system and beyond will also require smaller and cheaper spacecraft and systems. We've already made significant strides. Viking for instance, cost over $3 billion in today's dollars . . . and took about a decade to develop. It was about the size of a car.

By contrast, the Mars Pathfinder took a quarter of the time to develop. It cost less than one-tenth as much, and it was a fraction of the size.

The Pathfinder was just the first of what will be a continuous robotic presence on Mars for at least the next decade. The costs and the size of the spacecraft systems keeps coming down . . . but capability keeps going up.

We plan to get the size of one of these spacecraft down to about the size of an average television. Ultimately, we are talking about spacecraft -- nano-spacecraft -- that weigh less than one kilogram. They will fit in the palm of your hand. The entire avionics will be on one chip.

We will also need to drive materials and design tools . .. because these missions will be operating in some of the harshest environments. We will be entering atmospheres at heating rates 10 times higher than Apollo encountered on Earth reentry.

Right now, for instance, the limiting operating temperature inside critical components of aircraft engines -- or rockets or high-alloy car engines -- is about 1700 degrees.

In the future, with advanced materials like ceramic composites, we'll bring that temperature up to about 3000 degrees.

That will mean significant improvements not only in fuel consumption . . . but in emissions . . . and reliability. And at the same time, we will bring down the weight and cost. A moment ago, I mentioned Apollo. Back then, apart from the few astronauts in the spacecraft, all of the brain power was on the ground. But if we're sending humans to Mars -- or anyplace millions of miles away -- communications are going to take too long.

So at NASA, we want to develop fully autonomous outposts. If you think about the Shuttle Mission Control . . . for every person you see, there are many others backing them up. Launching the Shuttle takes thousands of people ... and hundreds of millions of dollars.

I'll use the Pathfinder again for contrast. From beginning to end .. .that mission took about 50 people. Total. Future missions will require only a dozen or so.

As we move into the future . . . the days of 100 to 1000 people in the back room will be something of the past.

That's what I mean when I talk about a "faster, better, cheaper" NASA.

Just think of the impact advanced information technologies and other breakthroughs will have on power plant operations. . . on package delivery businesses . . . and on the automotive industry.

These are the tools we need.

Now the question is, how do we get from here to there? Not just from Earth to Pluto. But from where engineering design culture is today . . . to where it needs to be -- and must be -- for the missions of tomorrow.

For a long time, engineering was a pencil to paper culture. Everything was based on classical engineering theory transferred into handbooks. And for those of you too young to remember . . . in the lower left-hand corner, you will see an antiquated device we called the slide rule. That's what I trained with.

In the 60s, we went to the electronic drafting boards that provided wireframe computer modeling. We used major mainframe computers and the analytical model interaction was through data cards and punch cards.

From there we went to distributed terminals . . . using light pens and touch screens.

In the mid 70s, we were using solid models to represent geometry and three-dimensional surface contours.

The major problem was the incompatibility of individual discipline analytical models with the geometric structural representation.

Too much time and resources were wasted on developing translational capability between diverse disciplines . . . like aerodynamics . . . thermal . . . structures and controls.

The traditional design process was sequential with separate discipline groups. We used individual analytical tools and system design was optimized at the discipline level not the system level.

Data and design information had to be moved from one group to another . . . a task accomplished by people carrying large piles of paper.

I'm sure there are a few of you who remember the many large mylar drawings used for manufacturing. (this was our transfer device . . . That's why God gave us engineering change orders)

About 20 years ago, we merged the design process with manufacturing -- the emergence of CAD/CAM.

This significantly reduced design cycle, process time and engineering change orders.

This trend has led to concurrent engineering -- the use of digital data sets for linking diverse disciplines.

The best example for concurrent engineering is the Boeing 777 aircraft development. At the peak of design work, 238 design teams involving 6,000 engineers . . . using data from 4,000 world-wide computer terminals . . . manipulated 3 trillion bytes of information . . . that represented 20,000 design releases.

It can be a bit overwhelming.

Today, we have very efficient and qualified product teams. But we still have a disconnect from discipline to discipline. We still don't have a common database . . . but rather many distributed, unconnected databases across engineering disciplines and manufacturing.

NASA is working hard to break this log-jam.

We have what we call our Product Design Center at the Jet Propulsion Laboratory. By bringing disciplines together, it has provided us with the ability to reduce analysis of mission design concepts from half a year to two weeks.

Now, this only includes preliminary design. We have yet to hit detailed design, manufacturing and operations. That's next. And industry is already working on some of these specific, near-term, focused areas.

Boeing is looking at simulating manufacturing of both fighters and transport aircraft.

One of their programs, called DMAPS, is focusing on engineering realism in modeling and incorporating it into producable aircraft.

Boeing is also looking at simulating the manufacturing process for large scale transports.

And Lockheed Martin is looking at how they can use this technology to create a virtual product manufacturing environment for the F-22. (pause)

Despite all of this effort, we still can't do total end-to- end product life cycle simulation.

That is a broad goal for NASA.

First, because of the sequential nature and limitations of our tools, there is still far too much uncertainty throughout the life cycle of a product.

Second, there's a lot of people involved. And we have just begun to address the geographically distributed nature of what we do.

Third, a point that really binds the first two, is that we need to capture design knowledge earlier in the design process.

And fourth -- the biggest challenge yet -- learning to deal with the unprecedented quantity of data and converting it into usable knowledge . . . finding the information needle in the electronic haystack. Having the database information we need. . . when we need it.

Given these four issues, the problem NASA and industry faces in developing a product is we have to commit a large percentage of the cost . . . when we only have a small percentage of knowledge.

And the more we commit and incur costs in any design process, our flexibility to make necessary changes diminishes. We can make the changes . . . but only at the risk of overrunning cost and schedule. The result, sadly, is that we don't get an optimized design.

We're making progress . . . we're not where used to be. But we're not where we ought to be either.

We must eliminate the discrete steps of conceptual design, preliminary design, final design . . . as well as manufacturing training, maintenance and operations.

It is crucial that we have integration of all processes and similarity of tools . . . so we capture a high level of design knowledge before incurring any significant costs.

This will lead to a significant reduction in cycle time in new product development . . . avoid overruns . . . and give us an optimized design without having multiple reiterations. Design iterations will occurr in the virtual world . . . not the expensive hardware world.

So I'd like to share with you what I think we need to do close the gap between design knowledge and cost commitments. We call it the Intelligent Synthesis Environment.

It's not just updating tools. It's fundamentally changing the culture of engineering.

Right now, we have research activities going on in advanced computing and human interaction with the computing environment . . . virtual presence and product development. . .and knowledge-based engineering and computational intelligence.

The challenge -- if NASA's going to reach our goals . . . and if our country is to lead the world in new products and applications -- is to integrate these activities into a vision for future science and engineering.

Because if we do that, we will establish a revolutionary leap in engineering . . . the ability to conduct entire life-cycle simulation at any required fidelity scale.

That's what ISE is about.

These are the major components.

The first two deal with human computer interaction in a distributed, collaborative environment.

The other two have to do with the new simulation tools . .. and how we incorporate these tools into a seamless life cycle system capability.

And finally the key element -- the cultural change I think we need to inject into the creative process.

I'll discuss each of these elements.

First, human interaction. Simply put, this deals with the dynamics and interfaces between the human being and the computer.

What you are looking at right now are some examples of how virtual reality can be used today. As a field, virtual telepresence is advancing -- both in two and three-dimensional representations.

The Vision Dome, for example, is one of the most advanced concepts to date. It allows you to view things in full-scale 3-D without devices, like glasses, head trackers and wands. Unfortunately, most of the applications have been in the entertainment area . . . not engineering.

We need to be able to simulate and visualize our engineering processes in real-time with full, interactive control.

The way we interface with computing today is for WIMPS -- Windows. Icons. Menus. Pointing Systems.

But this is not the way we deal with our environment.

In the real world, we make decisions based on all of our senses. We interact and process various sources of information.

You can't drive cars this way. You can't fly an airplanes this way.

At NASA, we know that WIMPS won't get us to Mars.

Presently, virtual reality deals with sight/sound only. In the future it will encompass all of the senses -- including smell and touch.

That's why currently, we need to exploit the research being done to understand the brain's cognitive processes.

Hopefully, soon we will be able to use this knowledge to bring together the computer user and the computer environment to maximize performance.

Imagine operating a computer the same way we deal with our daily environment -- using all of our senses to shape our thoughts and actions.

This isn't the computer controlling humans . . . it's the exact opposite. It's maximizing performance of computational capability.

In fact, the Air Force is already looking at how this kind of advancement can help their pilots.

Another step we must take in the area of human interaction with computers is moving from data . . . to information . .. to knowledge . . . to intelligence.

This isn't just semantics. Think of pilots.

They will have a lot of stuff in front of them. Temperature. Pressure. Wind speed.

That's data.

Our pilot puts this data together and determines what is going on . . . maybe an engine is overheating because of a defective fuel valve.

That's information.

Further processing provides. . . why this is happening.

That's the knowledge.

And finally, when we know what to do before a failure occurs . . and how to prevent it from happening in the future.

Now that's intelligence!

Next -- building the infrastructure for distributed collaboration so we can take full advantage of diverse teams around the world.

We have been working with the Department of Energy on their Accelerated Strategic Computing Initiative. It's looking at how we can develop teraflop capability in performance.

That's a good start. But we need to get to a hundred to a thousand-fold increase -- petaflop capability . . . perhaps even beyond -- for the ISE vision.

We need to move into non-silicon, or non-electric, computers.   Maybe they will include both optical and biological computing.

We also need to increase our networking capability.

The amount of information flowing through the pipeline needs to increase from under a gigabit . . . where it is today .. . to one hundred to one thousand gigabits per second . .. or even higher.

There will be actual intelligence in the switchers and routers . . . or intelligent interfaces . . . something that doesn't exist in today's Internet.

And this increased networking ability will enable us to link computers, mass storage facilities, and people seamlessly. The Department of Defense has a program that is a starting point for how we link diverse teams together in a simulation- based conceptual design environment.

But we can take it a step further . . . into a high fidelity . . . high information content . . . distributed . . . virtual environment.

We can have a team in the northeast . . .

a team in the south . . .

and a team in the west . . .

all working together on the same project in a virtual design space.

Instead of taking the "Red Eye" teams can come and go electronically.

More important . . . this provides us with something that has been missing for too long.

Scientists and engineers can work together as part of a collaborative team in the engineering design process.

And they can do so while staying in their own offices and laboratories.

Because the work space is virtual, we are not limited to a laboratory here on Earth.

These teams can work together, using the full range of human senses (sight, sound, feel, etc.) on Mars . . . or any other planetary body.   And, again, because it is virtual, they can view, participate and communicate from their own creative perspective.

These future directions will free us from the keyboard and terminal.

The third part of ISE is the rapid synthesis and simulation tools.

In today's engineering culture, due to limitations in our models, we over-simplify the real world . . . and we rely on separate complimentary test programs to establish worst case operating and failure conditions.

In order to account for the uncertainty and to quantify the risk level, we need to move from the traditional deterministic methods to non-deterministic methods . . . like probabilistic approaches . . . neural networks . . . genetic algorithms and symbolic computing.

We have already achieved a very high level of sophistication in numerical simulations across many disciplines.

But what we need now is an even more rapid analysis and optimization capacity so we can close the design knowledge - cost commitment gap, I spoke about earlier.

Let's look at an example of both non-traditional methods and applications.

First a non-traditional method: neural networks -- which have the capacity to learn or adapt analogous to the human brain. This graph shows the capability of current neural networks. Today's technology limits us to about one billion nodal connections . . . and one billion nodal interactions per second.

But the human brain is more than one million times more powerful than that.

In other words, we have a lot of work in front of us. But we also have the potential for a very high pay-off.

Neural networks and other non-traditional methods will help us analyze and design systems, like smart materials and devices. Systems like these would overwhelm any traditional design synthesis approach.

It could involve material modeling that will allow us to design devices that integrate various physical properties .. . such as mechanical . . . electrical . . . magnetic . .. and thermal.

These devices can sense and respond to stimuli. For instance they will be able to adjust the shape of aircraft wings, suppress engine vibrations and control sensitive optics.

This will begin with the quantum mechanics of the individual atom. We will then synthesize molecules and begin to understand their interaction.

From there we will develop a better understanding of basic physical phenomena.

And ultimately, we will model entire large-scale processes leading to engineering design applications. And this will be done atom by atom.

By the way, this is why we need to get to petaflop capability like I mentioned earlier.

Finally, we need the tools to link the complete life cycle simulation capability. The simulation of a life cycle in this virtual collaborative environment . . . goes from mission requirements . . . to multi-disciplinary analysis and design . . . to simulation of manufacturing and virtual prototyping . . . to operations and repair . . . all the way through product disposal.

The virtual design process will also give us, with unprecedented detail, cost impacts and risk level assessment. And as I said before, we can bring together groups who have been previously divided.

For example, to build the Next Generation Space Telescope, we need scientists working on the optical performance for scientific measurements. . . . and the engineers working on implementation . .. on how we can achieve our goals with a cost-effective system.

We will have a real-time model. We will be able to walk through the design at any scale . . . from the chip level to the overall system. We will be able to see it in orbit . .. before we buy material and cut hardware.

To ensure that we have analytical models to verify real world behavior and failure mechanisms . . . we need to integrate analytical models development in real time with experimental testing.

Here, you can see (reference to screen) the testing of aircraft fuselage coupled with its analytical model . . . and how we capture new knowledge about behavior and failure mechanisms.

This approach will dramatically shorten the cycle time of product development by enabling a seamless flow from initial concept through final design and manufacturing. We hope to eliminate the sequential design process of today.

To date, industry has concentrated on simulation of manufacturing, planning and processes only.

We have simulators of the individual machine. And we have real time assessment of inventory flow control.

But we need to be able to simulate an entire factory before we build it.

From there, we can begin to simulate the operations. . . including repairs and how we maintain a system. On the screen, you can see of how they're beginning to do this at Marshall on the X-34.

This advanced simulation also provides us with a unique opportunity to look at training at the virtual prototype level . . . before any hardware is in place. This is being used at Johnson for space station training.

That brings us to the fourth component of ISE -- how do we achieve this future engineering capability?

To this point, there are a lot of unknowns. In these virtual environments, we don't know what fidelity we need. We don't know what scale is required. We just don't know yet how these collaborative, virtual teams are going to work.

These are fundamental issues. So, to address these fundamental issues and demonstrate this future collaborative design environment, we are looking to establish national . . . virtual . . . distributed testbeds. These testbeds are like nothing you've ever seen before.

They are geographically distributed computing environments that integrate hardware-in-the-loop . . . real time information operating systems . . . and all associated engineering design tools.

At NASA, we want to focus these testbeds in critical areas such as a high speed civil transport . . . reusable launch vehicles . . . Next Generation Space Telescopes . . . and human exploration to Mars.

And clearly, we want broad industry and academic involvement. Because this is not just about the aerospace industry.

I've dealt with the technical barriers.

Now the cultural barrier.

We need to realize that this is not just about technology. It's about people . . . and how people work and communicate on a global scale.

It's about a factory and design team in the United States . . . working with colleagues in Asia . . . working with colleagues in Europe . . . following the sun and cutting cycle time by a factor of three.

It's about a diverse global workforce enriching our lives. It's about government and universities realizing what is in front of us. And it's also about industry seizing the opportunity.

Because I firmly believe the crux of this cultural change will be management's acceptance and support of this new engineering approach for new product development and certification.

- Universities giving students hands-on experience and education
- University professors stressing more than the theoretical.
- Industry hiring students. Industry hiring professors in the summer
- Industry employees going back to school.

Right now, there are a lot of challenges in front of us . .. the need for shorter time to market . . . the need for lower life cycle cost . . . and the need for shorter development times just to name a few.

But these are outweighed by the promise and opportunities that form the framework for the new Intelligent Synthesis Environment.

20-25 years from now -- when our children and grandchildren are the engineers and scientists that run this country -- some of them might be working in the operations center to plunge a submarine underneath the icy ocean that we think covers Europa -- one of Jupiter's moons. Others may be preparing for a visit to Mars. They will have the training. Because when they're in college, they will have learned to use the tools we talked about today.

That's what we're about at NASA. Now let's get to work.

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